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MET O 3 TECHNICAL NOTE NO.22

NON-SINUSOIDAL FEATURES OF THE SEASONAL VARIATION OF TEMPERATURE IN MID-LATITUDES

By

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Contents

Summary

1. Introduction

2. The non-sinusoidal nature of the seasonal variation of temperature

3. Interpretation of the harmonics

4. Geographical variations in the harmonics of mean temperature

5. Differences in the harmonics of maximum and minimum temperature

6. Secular variations in the harmonics of temperature

7. Conclusions

References

Summary

Reasons for the non-sinusoidal nature of the seasonal variation of temperature in mid-latitudes are discussed. They are then used to explain the geographical and secular variations in the second harmonic of temperature previously found by Craddock and Smith.

1. Introduction

The seasonal variation of temperature in mid latitudes is mainly, but not entirely, sinusoidal. Relatively well marked asymmetries in the march of monthly mean temperatures are illustrated in fig 1 for Yakutsk in Siberia and Reykjavik in Iceland. The departures from a purely sinusoidal annual cycle of temperature may be taken into account by using harmonic analysis and Craddock (1956a) has shown that two harmonics are sufficient to obtain an adequate representation of the seasonal variation of temperature. The non sinusoidal component will then be represented by the second harmonic.

In a series of papers, Craddock (1955, 1956a, 1956b) examined geographical variation in the first and second harmonics of mean temperature over the Northern hemisphere, Northern Europe, and the British Isles. Later, Smith (1984) examined temporal changes of these harmonics at Oxford, and illustrated the difference between those for maximum and minimum temperature. The purpose of this note is to discuss the reasons for the non-sinusoidal variation of temperature, and to explain the findings of Craddock and Smith.

2. The non-sinusoidal nature of the seasonal variation of temperature

In mid latitudes, departures from a purely sinusoidal seasonal variation of temperature may be expected for 5 reasons:-

(i) Solar elevation

A change in the solar elevation has more effect on the radiation received at the surface when the sun is low in the sky than when it is high. At 50°N, for example, a rise in the solar elevation from 16° at the winter solstice to 21° 38 days later produces a greater change in radiation than the decrease

from 63° to 58° as the summer solstice is passed. The changes in radiation received at the surface are therefore greater during the passage of winter months than in the summer. The effect on the seasonal variation of temperature is to make the winter trough sharper than the summer peak. The dates at which mean temperature reach their highest and lowest values are also affected. The increase in radiation as the sun's elevation increases through January is greater than the corresponding decrease during July. Hence the date of the seasonal extreme of mean temperature lies nearer to the solstice in winter than in summer. A corollary is that the fall of temperature in autumn is more rapid than the rise in spring.

(ii) Lapse rates

Mean lapse rates of temperature in the atmosphere vary seasonally, especially over the land, where they are greater in summer than in winter. The more stable the atmosphere, the smaller is the depth of the atmosphere that has to be heated or cooled. Over the continents, this factor contributes towards more rapid changes of temperature in winter than in summer, and hence a winter trough which is sharper than a summer peak.

(iii) Sea temperature

In winter, the surface layers of the oceans are well mixed and the vertical structure of sea temperature is approximately isothermal. In summer, however, the surface layers are warmer than those below and the depth of ocean which is being heated or cooled is much less than in winter (see, for example, Wells (1982)). It follows that sea temperatures change more readily in summer than in winter, and their seasonal variation is characterized by a summer peak which is much sharper than the winter trough.

(iv) Seasonal changes in the relative importance of radiation and advection

Compare two locations with different climates, the first calm and sunny, the second overcast and windy. One would clearly expect the first location to have the greater seasonal variation of temperature, with the dates of the maximum and minimum closer to the solstices than those at the second location. Consider next a single location where the summers are calm and

sunny and the winters cloudy and windy. The effect on the seasonal variation of temperature is to make the summer peak sharper than the winter trough.

(v) Seasonal changes in the frequency of northerly and southerly winds

In the northern hemisphere, a predominance of northerly winds in winter and summer and southerly winds in spring and autumn will make the winter trough sharper than the summer peak. A greater frequency of northerly winds in the first halves of winter and summer compared to the second halves of those seasons may advance the winter trough and delay the summer peak. Although changes in the frequencies of cold and warm winds do occur, they generally have a periodicity of 12 rather than 6 months, and therefore affect the first, rather than the second, harmonic.

3. Interpretation of the harmonics

The combined effects of the first and second harmonics are described by Craddock (1956b), but are repeated here for convenience. Figure 2 demonstrates the addition of a first harmonic with trough and peak in January and July respectively to a second harmonic whose amplitude is 20% of the first. Figures 2a and 2b show that when the peak of the second harmonic is in phase with that of the first, the summer peak is sharpened. When the peak of the second harmonic is delayed by 46 days, figs 2c and 2d show that the date of the winter trough is advanced while that of the summer peak is delayed. If the second harmonic peaks 92 days after the first, it is the winter trough which is sharpened. Thus if the peak of the second harmonic lags behind the first by up to 46 days, the effect is that of a sharp summer peak combined with an asymmetric rise and fall of spring and autumn temperatures. If the lag of the second harmonic is between 46 and 92 days, the asymmetric rise and fall of temperature is combined with a sharp winter trough.

The second harmonic does not express explicity the two main features of the non-sinusoidal behaviour of temperature. The amplitude does not distinguish between sharp summer peaks or winter troughs, while the phase compounds this information with the asymmetry in the spring rise and autumn fall of temperature. A description of the non-sinusoidal variations in temperature would therefore be made clearer by the use of two 'second harmonics' with phases fixed at 0 and 46 days with respect to that of the first harmonic. The first of these 'second harmonics' would then measure the relative sharpness of the summer peak to the winter trough, while the second would contrast the rate of spring rise in temperature to the autumn fall.

4. Geographical variations in the harmonics of mean temperature

Craddock (1955) has calculated the first and second harmonics of mean temperature for 305 stations in the northern hemisphere using monthly mean temperatures for 1921-40. The first harmonic simply reflects the increased amplitude and advanced phase of temperature variations over the continents with respect to those over the oceans. The main findings concerning the second harmonic are reproduced in figs 3 and 4.

Fig 3 displays the difference in phase between the first and second harmonics of mean temperature. This is shown to lie between 0 and 45 days over the oceans and Arctic, and between 45 and 90 days over the continents. A faster autumn fall than a spring rise of temperature is therefore indicated, combined with a sharp summer peak over the oceans and a sharp winter trough over the continents. These features are in accord with the relative importance of radiation and sea temperatures in determining the seasonal variation of air temperatures. In the Arctic, the long winter night also contributes towards the establishment of a flat winter minimum. Over the oceans and northern continents, the relative importance of radiation to advection in the climate is greater in summer than in winter. This enhances the well defined summer peak over the ocean,

where there is a feedback on sea temperatures, and sharpens the flat summer peak over the continents. Over the more southerly continental areas, the monsoonal climate causes the relative importance of radiation to be greater in winter than in summer and this enhances the sharp winter trough in those regions.

Fig 4 displays the ratio of the amplitude of the second harmonic to that of the first, and shows that the second harmonic is more important over the oceans and towards the tropics than over the temperate continents. The sea temperature is seen to introduce a larger non-sinusoidal component over the ocean than radiation does over the continents. In the tropics, of course, the second harmonic assumes greater importance because of the occurence twice in a year of the overhead sun.

5. Differences in the harmonics of maximum and minimum temperature

Maximum temperatures respond to solar radiation more rapidly than minima which are more dependent on dewpoint and therefore on sea temperatures. These differences can be seen in the findings of Smith (1984) who reports that, at Oxford, for example:-

(i) The phase of the first harmonic of maximum temperature is 8 days ahead of that for minima.

(ii) The phase difference between the first and second harmonics is 30 days for maxima, but only 5 days for minima. This shows that the asymmetry in the seasonal rise and fall of temperature is pronounced for maxima, but almost absent for minima.

(iii) The ratio of the amplitudes of the second to the first harmonic is 13% for minima but only 7% for maxima. This shows that for the maritime climate of the UK as exemplified by the records for Oxford, the relative sharpness of the summer peak to the winter trough is greater for minima than for maxima.

6. Secular variations in the harmonics of temperature

Using data from 1861 to 1980, Smith (1984) showed that the amplitude and phase of the second harmonic of temperature at Oxford have undergone considerable changes with time. It will now be shown that these variations are an expression of changes in the continentality of climate at Oxford.

Increasing continentality is associated with changes in the relative sharpness of the winter trough to the summer peak. For minima, in which the asymmetry in the seasonal rise and fall of temperature is small, this will be associated with a decline of a second harmonic which is in phase with the first, followed by the growth of a second harmonic which lags the first by around 92 days. For maxima, the asymmetric rise and fall of temperature prevents the amplitude of the second harmonic from falling to zero. Increasing continentality is, therefore, associated with an increase in lag of the second harmonic with respect to the first. As discussed in section 3, a phase lag of up to 46 days combines an asymmetric rise and fall with a sharp summer peak, while a lag of between 46 and 92 days combines the asymmetry with a sharp winter trough.

Smith's results are summarized in fig 5. It can be seen that an increase in phase difference between the first two harmonics of maximum temperature is highly correlated with a decrease in the amplitude of the second harmonic of minimum temperature (note the inverted scale), and with the amplitude of the first harmonic of minimum temperature. The last named may be regarded as a direct measure of the continentality of climate.

7. Conclusions

Departures from a purely sinusoidal annual cycle of temperature are due to the effects of solar elevation, sea temperatures, and the relative importance of radiation and advection at a particular location. The non-sinsoidal behaviour is characterised by two main features, namely a difference in the

sharpness of the summer peak compared to the winter trough, and an asymmetry in the spring rise and autumn fall of temperature. These features are best represented by two 'second harmonics' with phases fixed at 0 and 46 days with respect to that of the first harmonic. These characteristics can, however, also be related to the phase and amplitude of the conventional second harmonic, and used to explain the geographical and secular variations in these parameters found by Craddock and Smith.

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1956 b The harmonic representation of the annual temperature variation in different parts of the British Isles. Met Research Paper No.970 , Air Ministry, London.

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FIG 1 - SEASONAL VARIATION OF TEMPERATURE AT YAKUTSK AND REYKJAVIK

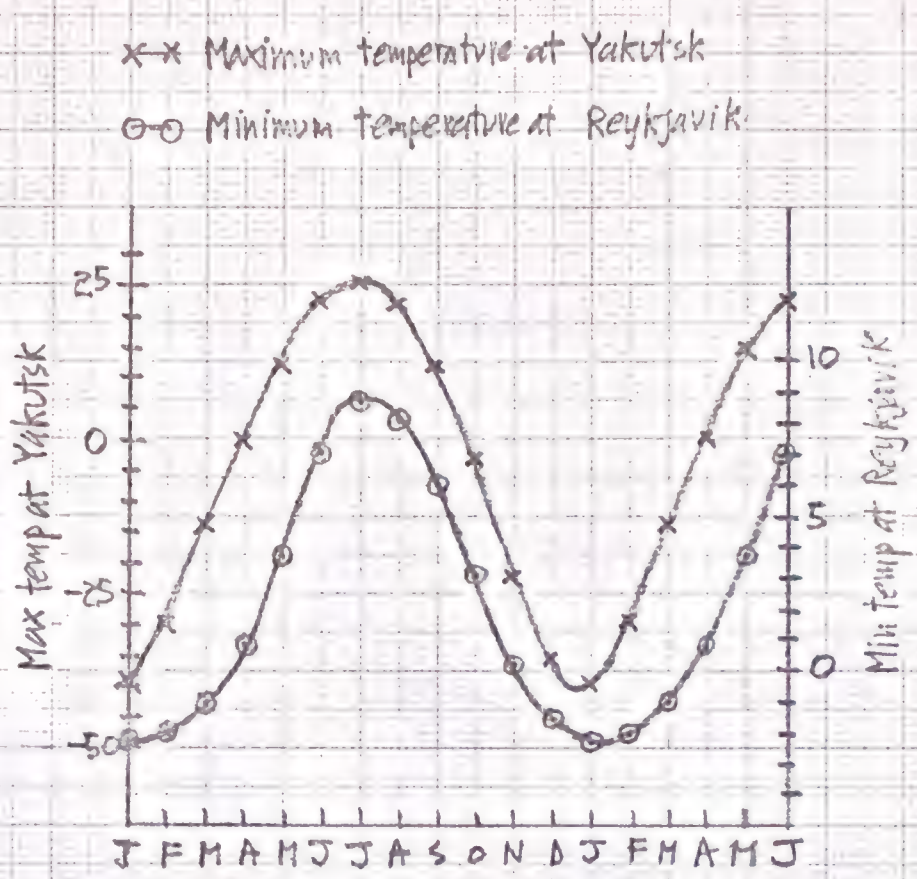

FIG 2- COMBINATION OF FIRST AND SECOND HARMONICS.

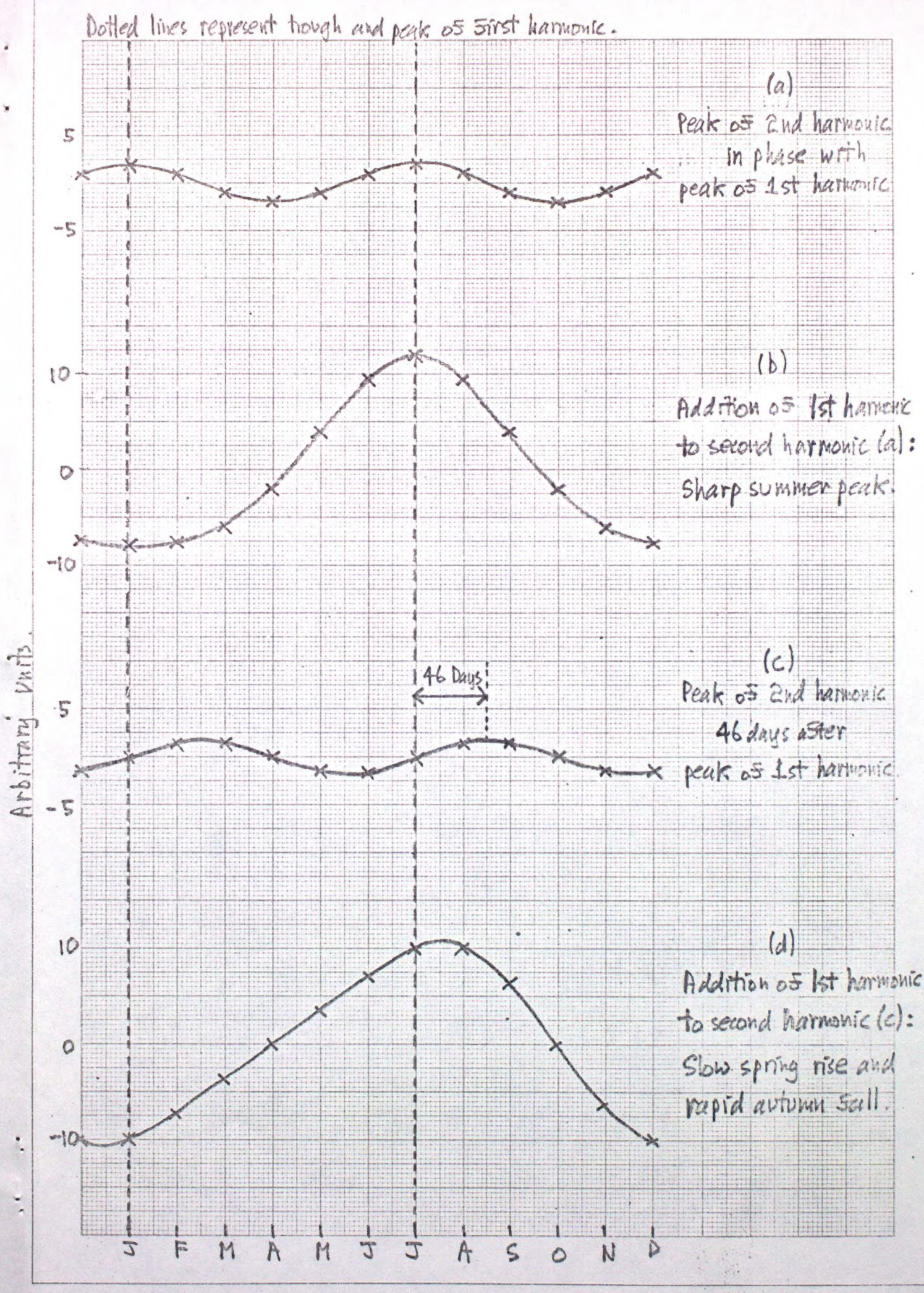

FIG 3 - DIFFERENCE IN PHASE (DAYS) BETWEEN FIRST AND SECOND HARMONICS OF MEAN TEMPERATURE

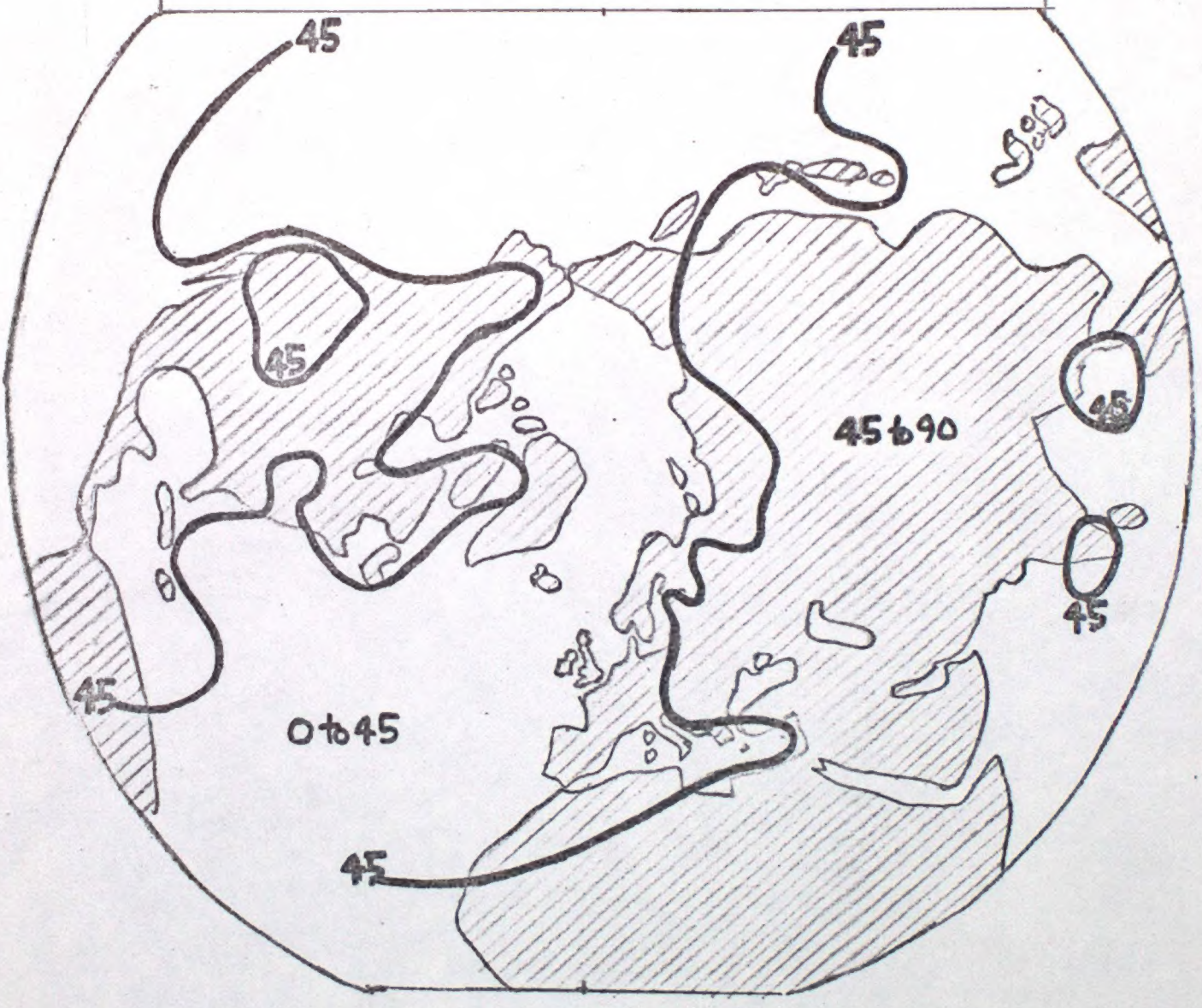

FIG 4 - RATIO OF AMPLITUDE OF SECOND TO FIRST HARMONIC OF MEAN TEMPERATURE (%)

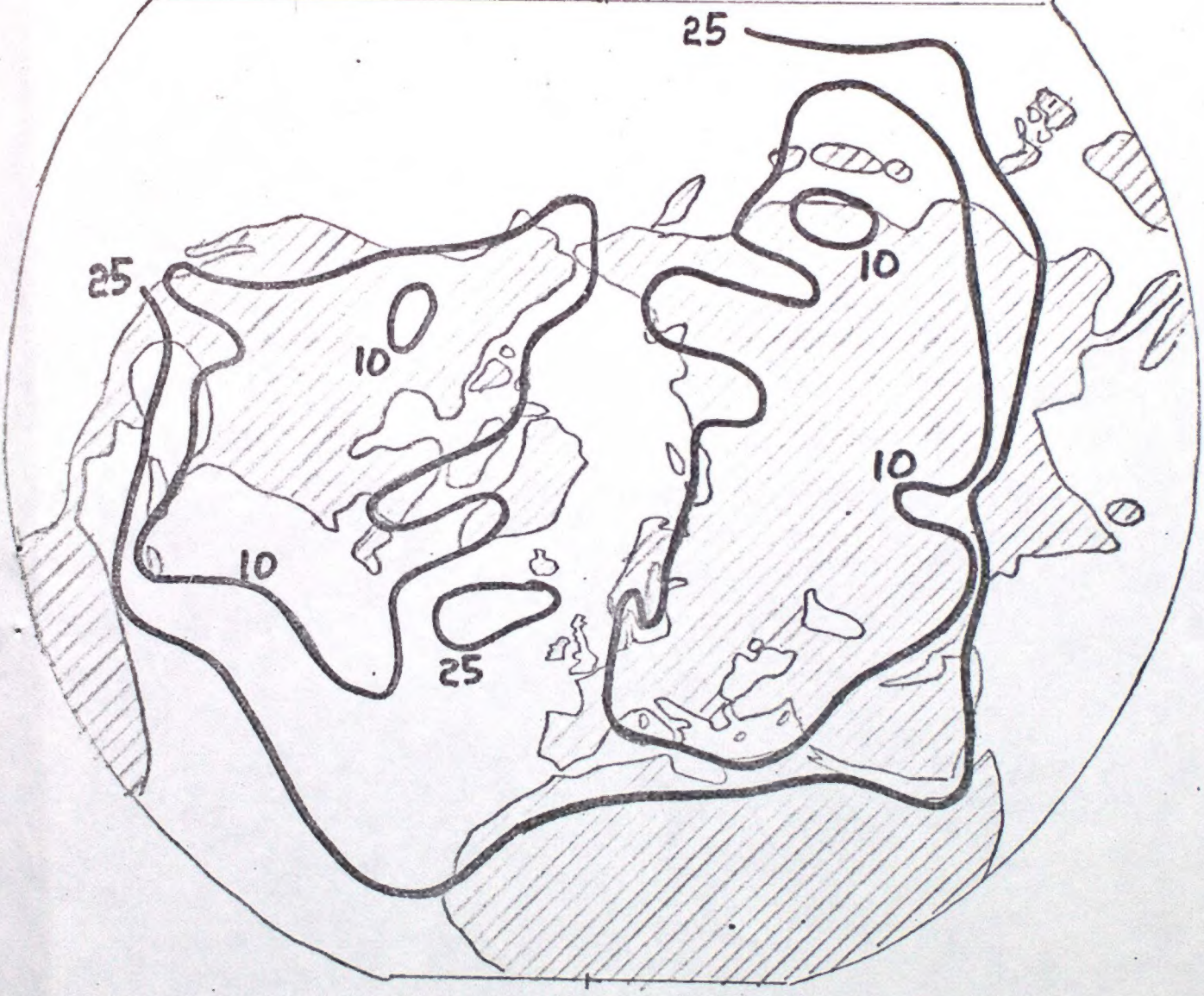
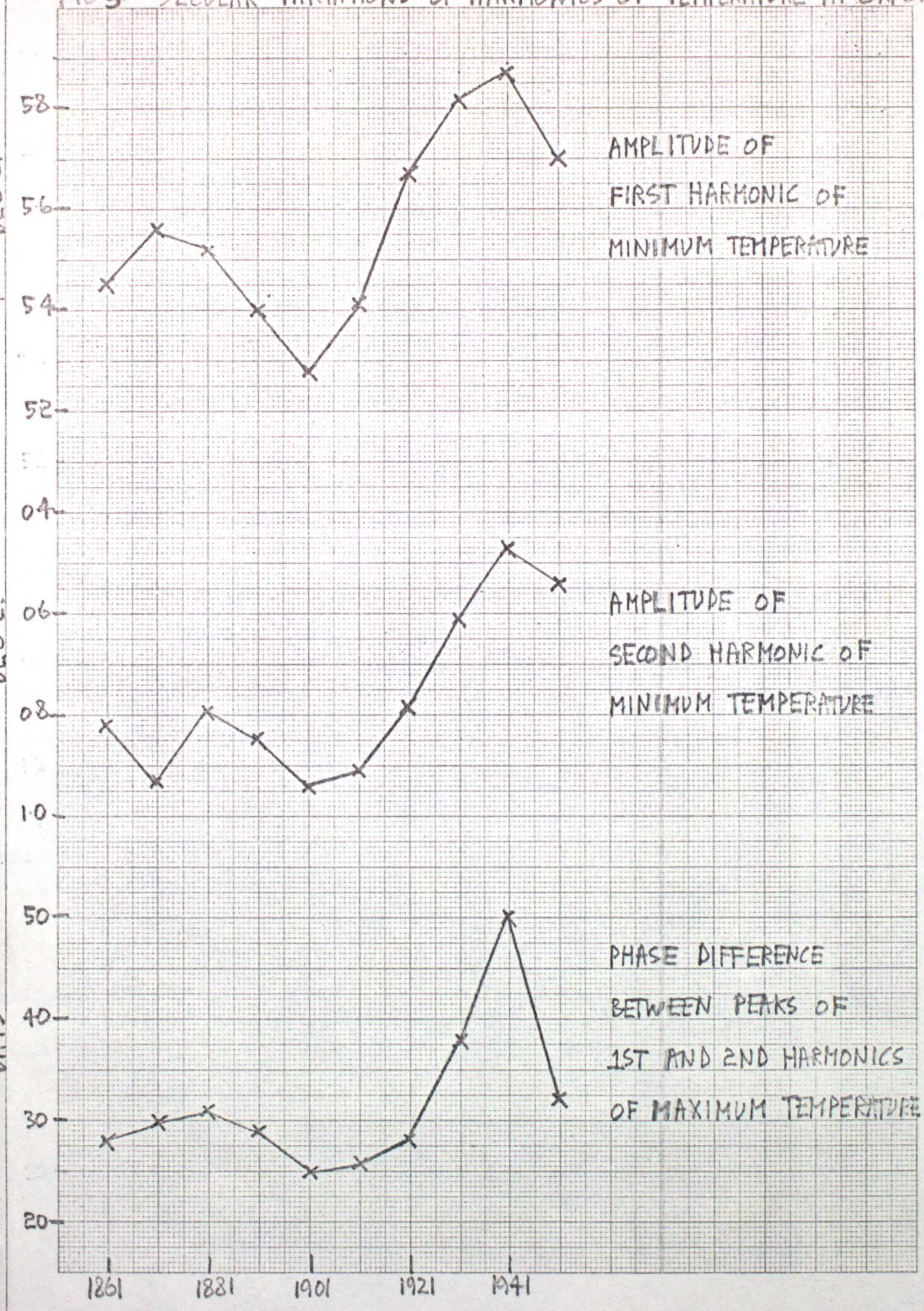
FIG 5 - SECULAR VARIATIONS OF HARMONICS OF TEMPERATURE AT OXFORD.